Plankton Production Biology

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LONG-TERM GOALS

I continue to study geographic and seasonal distributions of hydrographic, chemical, and planktological phenomena in the northern, central, and eastern Arabian Sea. Also, I comment on general oceanographic or ecological principles. The attempt to open windows to the Russian oceanographic literature by arranging for publications of translations of monographs by Russian-language authors continues.

OBJECTIVES

1. *To study the long-term (four decades) stability and short-term (days) variability of the oxygen minimum zone (OMZ) in the Arabian Sea between 64 and 87˚E*. This OMZ is the thickest of the three open-sea regions of the world's ocean for water column denitrification, important for the maintenance of the ocean's inventory of bound nitrogen but also as generating the greenhouse gases N_2O and CH_4. Considering an estimated mean residence time of the OMZ water of about ten years, the available data extending over four decades should be adequate but the large variability in space and time may form obstacles for establishing trends or the absence thereof.

2. *To open windows to the Russian oceanographic literature* by arranging for publications of translations of monographs by Russian-language authors.

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WORK COMPLETED

1. The lack of understanding of the high winter chlorophyll levels in the two subpolar HNLC regions was briefly reviewed (Banse, 2004).

2. Two of so far three monographs based on Soviet/Ukrainian oceanographic work (two translations, one newly commissioned and written from the outset in English) now have, finally, reached the stage of being prepared for distribution, after one had been submitted to the press in 2000 (the translating and editing were supported by ONR several years ago):

Sazhina, L.I. (2005; Russian original, 1987) *Reproduction, Growth, and Production of Marine Copepods* (140 pp., with 35 figures and 55 tables). Universities Press/Orient-Longman, Hyderabad, India. Suggested U.S. retail price, $ 25.95. (Abstract under Results.)

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Banse, K. and S.A. Piontkovski, editors (2005) *The Mesoscale Structure of the Epipelagic Ecosystem of the Open Northern Arabian Sea* (248 pp., with 184 figures and 29 tables). Universities Press/Orient-Longman, Hyderabad, India. Suggested U.S. retail price, $ 35.-. (Abstract under Results.)

3. The description of the development of our understanding of the distribution of phytoplankton chlorophyll, from the first in-situ collection to the Color Scanner, in the open Arabian Sea was contributed to a review paper (Wiggert et al., 2005).

RESULTS

1. *Winter chlorophyll in the subpolar HNLC regions.*

Initially supported in the U.S. also by ONR, considerable efforts during the last 15 years were devoted by several countries to the High-Nitrate, Low-Chlorophyll regions (HNLC) regions of the open sea, which constitute about one-quarter of the world ocean area. The unutilized nutrients pose a scientifically challenging issue, but also figure in deliberations of reducing the man-made increase of atmospheric CO_2 (a greenhouse gas). The ultimate cause of the HNLC condition is scarcity of iron, but proximally the chlorophyll level is largely governed by grazing of the prevailing small phytoplankton cells and not the phytoplankton cell division rate. While fertilization with iron of relatively large patches of open sea at various latitudes has clarified part of the situation, the understanding of the functioning of the undisturbed, natural ocean is lagging (cf. Landry et al., 1997). Especially puzzling is that in the two sub-polar regions, situated at intermediate latitudes with strong seasonal changes of incident and underwater irradiance and, hence, phytoplankton cell division rates, the chlorophyll concentrations essentially do not change with season. About a decade ago and largely prior to the various sub-polar JGOFS (Joint Global Ocean Flux Study) expeditions, I had published a long treatment of the subject (Banse, 1996). During the last year (Banse, 2004, see Publications) I reminded the scientific community of the fact that a subproblem of the HNLC issue, relevant for more than one-tenth of the ocean area, is the maintenance of winter chlorophyll levels in the two sub-polar HNLC regions, which are much higher than those in the temperate and subpolar open North Atlantic or the temporally ice-covered high latitudes and which, moreover, are about as high as the summer levels (there is no spring bloom). More field work would be needed - and that in rough seas.

2.a. L.I. Sazhina (translation of the original published in Russian in 1987) *Breeding, Growth Rates, and Production of Marine Copepods*. With 35 figures and 55 tables, originally on 155 small-format pp.

The monograph treats reproduction and growth of Copepoda (Crustacea), the group that contributes the major part of the biomass of zooplankton collected with plankton nets in salt- and freshwater. The basis of the book is many years of experiments and field research by the author and her colleagues in the Black and Mediterranean seas and warm parts of the Atlantic, Pacific, and Indian oceans. Based in part on new methods, field values of clutch size, developmental time, and intervals between clutches are reported for 85 dominant species, which is a very large number as compared to data published in the English- and French-language literature. Changes in reproductive characteristics of some populations are established and geographic distributions of generative production as dependent on ecology and habitat are shown for the first time. Life cycles of 29 species are described, as well as changes in growth indices and oxygen consumption during the individual development of ecological groups. Quantitative rules of somatic and generative production in different ecological systems are found for some species.

Finally, the necessity of an ecological approach in modeling of the production process is substantiated, which applies to salt- and freshwater. The significance of the monograph rests both on the volume of work reported for the first time, as well as on opening windows to the large Russian-language marine-biological literature by publishing this translation. The observations are not subject to becoming outdated, and the underlying biological principles apply also to freshwater copepods.

2.b. K. Banse and S.A. Piontkovski (editors and contributors) *The Mesoscale Structure of the Epipelagic Ecosystem of the Open Northern Arabian Sea.* Fifteen chapters with 184 figures and 29 tables on 248 pp.

The newly commissioned book concerns a comprehensive 1990 expedition with 77 stations by Russian-language (Ukrainian) authors, with some references to work during the early 1980s in the same area by other expeditions using the same grid design. Incidentally, in contrast to the British, Dutch, German, Indian, and United States expeditions, which sampled in the Arabian Sea along one or few transects even during the 1990s, most of the Soviet and Ukrainian expeditions worked on grids of stations, usually with 0.5 or 1.0 degree station spacing (55 and 110 km, respectively). This salient difference allows three-dimensional treatments including modeling.

The 1990 observations, not published previously, range from hydrography (including calculated vertical velocities) through nutrients, bacteria, phytoplankton, micro-, meso-, and macro-zooplankton, to mesopelagic (mid-water) fishes and squid. All chapters emphasize the processes in the upper layers (mostly 150 m). Besides the normal plankton collections, as well as rate measurements for bacteria and phytoplankton, on-board experimentation with animals for obtaining feeding, respiratory and developmental rates were conducted. Identification of the meso-zooplankton (mostly copepods) to species and developmental stages permitted approaches to population dynamics and good production/ material flux estimates, which are normally not obtained.

The idea behind commissioning the volume was to not only make the results of the particular expedition known, but also to draw attention to previous Russian/Ukrainian work: Because of the language barrier, next to no results of the numerous Russian and later Ukrainian expeditions to this region were referred to in the proposals for and the reports on results of the Arabian Sea expeditions of the mid-1990s by the above-named five countries, conducted under the international Joint Global Ocean Flux Study (JGOFS) umbrella. This must not be allowed to happen again.

3. *Interdecadal, interannual, and short-term variability of oxygen and nitrite in the oxygen minimum of the central Arabian Sea* (K. Banse and J.R. Postel, Seattle; S.W.A. Naqvi and P.V. Narvekar, National Institute of Oceanography, Dona Paula, Goa, India; D.A. Jayakumar, Dept. of Geosciences, Princeton University) (in preparation for Global Biochemical Cycles). We address the question, "Is the Arabian Sea oxygen minimum stable in time?" The answer is of broad biogeochemical significance because here, one-quarter to one-third of the marine water column denitrification takes place: That process removes the bound nitrogen that is perpetually added to the oceans by molecular nitrogen (N_2) fixation of some phytoplankton species, lightning, dust in rain, and rivers. Since sedimentation with burial is a small part of the marine nitrogen budget, without denitrification the sea would have become a cesspool eons ago. The removal of bound nitrogen, principally by reduction of nitrate, however, proceeds only in the near- or total absence of dissolved oxygen. Nitrite (NO_2^-) is generated as an intermediary of denitrification. Besides the release of N_2 as the end product, the O_2-deficiency enhances the production of nitrous oxide (N_2O) and methane (CH_4), two important greenhouse gases. Because the residence time of the water in the OMZ of the Arabian Sea is estimated to be close to ten

years, the now existing four decades of scattered observations permit the study of the temporal stability of the oxygen minimum. (Parts of this still ongoing work was presented in earlier Annual ONR Reports) The upper depth for our open-sea investigation (150 m) is near, but below the bottom of the euphotic zone where O_2 is generated, and data from below 500 m are scarce. The observations, still quite scattered in spite of the various data centers, are grouped into 12 boxes of 1 deg. of latitude and 2 deg. of longitude between 8 and 21°N along the central meridians of 65 and 67°E, and the horizons near 150, 200, 300, 400, and 500 m are being investigated. For nitrite in the same area, depths, and period, trends in observations of >0.5 μmol L^{-1} NO_2^- are especially interesting, since they indicate active denitrification. In the last Annual Report I observed that the OMZ proper, between approximately 15 and 21°N and 64 and 68°E, significant ($p \leq 0.10$) temporal changes of O_2 concentrations were not found except near 15 and 18°N and between 66 to 68°E, where the median decline over four decades was almost 0.10 mL L^{-1} (4 μmol L^{-1}) O_2. For the same decades most regression slopes of nitrite did not differ significantly from zero, similarly to oxygen, and the nitrite slopes did not form a mirror image of oxygen. Since the last report, however, we have discovered significant hydrographic and chemical seasonality down to 500 m depth. Previously, Ramesh and Krishnan (2005) using Levitus' means, had reported marked warming during the southwest (summer) monsoon (SWM) to 200 m, well into the lower pycnocline. Using T-S diagrams for medians of our data, we confirm this diapycnal seasonal temperature change, but add isopycnal shifts at the 300-m to 500-m horizons in the OMZ. Moreover and more puzzling, the oxygen concentrations even at these lower depths vary seasonally, the highest values being observed during the northeast (winter) monsoon, which often are double those of the SWM. In both seasons in the mentioned latitudinal interval of 15-18°N, the slopes of regressions on years are negative, as for the entire years. Currently, we try to understand the mechanisms at work and look forward to the completion and publication of the results.

IMPACTS

The appearance of two books in 2005 will help to open windows to the large Russian-language oceanographic and marine-biological literature, which is largely unknown in this country.

The paper by Wiggert et al. (2005) on chlorophyll distribution and modeling is going to remain relevant for some time to come, also because the interest of much of the scientific community has turned away from the Arabian Sea and not many new data wil be forthcoming soon.

The oxygen minimum zone (OMZ) in the central Arabian Sea is one of the three major OMZs of the world's ocean. In this OMZ, one-quarter to one-third of the marine water column denitrification takes place. The region appears as teetering on the verge of actual anoxia, with unknown impacts on N_2O and CH_4 production. For the Arabian Sea, our forthcoming paper will at least discourage future attempts of establishing oxygen or nitrogen budgets from single sections by ships, in view of the marked small-scale spatial and short-term temporal variability to be demonstrated.

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Landry, M.R. and 12 co-authors (1997) Iron and grazing constraints on primary production in the equatorial Pacific: An EqPac synthesis. Limnol. Oceanogr. 42: 405-418.

Ramesh, K. V., and R. Krishnan (2005) Coupling of mixed layer processes and thermocline variations in the Arabian Sea, J. Geophys. Res. 110, C05005 doi:10.1029/2004JC002515.

RELATED PROJECTS

I continue to stay in contact with India's National Institute of Oceanography in Goa and occasionally advise the director.

PUBLICATIONS

Banse, K. (2004) Open questions after JGOFS: Winter chlorophyll levels in the two subpolar HNLC regions. US JGOFS Newsletter (November 2004): 14 [non-refereed?].

Sazhina, L.I. (2005) *Reproduction, Growth, and Production of Marine Copepods* (140 pp., with 35 figures and 55 tables). Universities Press/Orient-Longman, Hyderabad, India. (translation edited and prepared for publication by K. Banse)

Banse, K. and S.A. Piontkovski (editors and contributors) (2005) *The Mesoscale Structure of the Epipelagic Ecosystem of the Open Northern Arabian Sea* (248 pp., with 184 figures and 29 tables). Universities Press/Orient-Longman, Hyderabad, India. (With three brief chapters by K. Banse.)

Wiggert, J.D., R.R. Hood, K. Banse & J.C. Kindle (2005). Monsoon-driven biochemical processes in the Arabian Sea. In: *The Arabian Sea of the 1990s: New biogeochemical understanding*, edited by S.L. Smith. Prog. Oceanogr., 65: 176-213 [refereed].